AN EXPLORATORY STUDY OF VOICE QUALITY IN ESOPHAGEAL SPEECH

A Thesis

Presented to

the Faculty of the Department of Speech

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

---

by

Jacqulyn Burkart Mannix

August 1968

ACKNOWLEDGMENTS

The writer gratefully acknowledges Dr. Ronald W. Wendahl for his inspiration and significant contribution to the experimental design, procedural techniques, and data analysis of this thesis.

Gratitude is also expressed to Dr. James A. Rice for his continued encouragement and the many hours he devoted to the statistical treatment of the data, and to Dr. E. K. Jerome for his valuable criticism and guidance during the writing of this thesis.

Special acknowledgment is expressed to the eight subjects for their cooperation and willingness to participate in this study.

To my companions, especially Diane Linklater and Belinda Cole, my sincere appreciation is expressed for their constant moral support and help with the Visicorder analysis.

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ABSTRACT OF THESIS

This study was designed to investigate the relationship between judged pleasantness of esophageal vocal productions of an isolated vowel and the amount of jitter present in the acoustic signal. Secondary variables considered included: the relationship between fundamental frequency and judged vocal pleasantness of phonations, and the amount of "wetness" that listeners perceived in the phonations.

Eight esophageal speakers phonated the vowel /æ/ several times. Two phonations from each subject were chosen for exploration. Master tapes were compiled in two designs: one, in pairs for comparison, and one, for rating on a seven-point scale.

The two phonations were subjected to Visicorder analysis. Hand measures of the tracings were used to compute fundamental frequency and jitter ratios. The jitter ratios were computed arithmetically by dividing adjacent frequencies, always using the smaller figure as denominator.

Thirty-four judges performed three listening tasks. They were asked to judge which of each pair of stimuli was most pleasant; rate 80 stimuli according to degree of pleasantness; and rate the amount of wetness present in the phonation.

Parametric procedures were followed in analyzing the rating scale data: nonparametric computations were used for the paired-comparisons data.

Results of this study indicated that the amount of wetness

perceived during the phonation of an isolated vowel was a strong determinant of judgments of unpleasantness in esophageal speakers. The amount of jitter was less important to the judgments than was wetness. Fundamental frequency did not appear to be related to the pleasantness judgments.

This study was limited in scope and additional research on voice quality in esophageal speech should be carried out.

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CHAPTER I

STATEMENT OF THE PROBLEM AND REVIEW OF THE LITERATURE

The description of voice quality has been of concern to researchers for many years. Until the past decade, classification of different types of voice was limited to use of subjective terminology and definitions. With the innovation of better equipment and methods of research, significant quantitative measurements of both normal and abnormal phonations of the intact larynx were made possible. The application of these newer techniques to alaryngeal speech also appears advisable since the experimental data regarding the voice quality of those who speak without a larynx is limited.

I. STATEMENT OF THE PROBLEM

One purpose of this study was to determine whether there were significant differences in voice quality among esophageal speakers which can be determined and agreed upon by listeners. Another purpose was to investigate the relationship between wave to wave shifts of period length in alaryngeal voice and listener judgments of excellence of phonation. Since relatively little is known about the vibratory pattern of esophageal speech, this was regarded as strictly an exploratory study. The primary question being posed was whether regularity in esophageal vibratory activity affected a change in judgmental responses of excellence.

II. LITERATURE ON ALARYNGEAL SPEECH

Various attempts have been made to describe the physiological, perceptual, and acoustical properties of alaryngeal speech. In large part, investigations of alaryngeal speakers have paralleled studies designed to determine the characteristics of normal speech and voice production.

The mechanism of voicing in the laryngectomized, the neoglottis or pseudoglottis, has been intensively investigated through the use of roentgen-cinematographic analysis and the measurement of pressure variations in the pharynx and esophagus during intonation (1, 2, 7, 8, 11). Several types of alaryngeal speech have been cited in the literature. Commonly accepted classifications are buccal, pharyngeal, and esophageal.

According to Diedrich and Youngstrom (8), buccal speech is produced by trapping air between the cheeks and the teeth or the alveolar ridge and the tongue. In pharyngeal speech, the air chamber was said to be located in the pharynx with the neoglottis formed by the tongue against the palate, the pillars of fauces, or the posterior pharyngeal wall (8). Buccal and pharyngeal speech were reported to sound similar, although neither was considered particularly intelligible due to the dual function of the tongue as a vibrator and an articulator. In esophageal speech, the neoglottis was considered to be at the pharyngo-esophageal junction, typically located between the levels of the fourth to sixth cervical vertebrae (8, 11). Air necessary for phonation was observed to be trapped within the lumen of the esophagus and then released to produce vibration in the area of the neoglottis.

Since esophageal speech appears to be the most satisfactory for laryngectomees, this method of speaking has been the most widely investigated (1, 6, 7, 8, 11, 26). Recent research by Diedrich and Youngstrom (8) supports the earlier experiments of Kirchner (11). In general, these researchers found no significant relationships between good esophageal speech and variations in the following anatomical variables: (a) the size of the hypopharyngeal lume, (b) the formation of the neoglottis as a thin band or as a broadly based mass, (c) the length of the vibrating segments, and (d) the amount of cephalo-caudal movement of the neoglottis. Width of the esophagus and palatal function, however, was found to be correlated with speech skill at the 0.01 level of confidence (8). As reported by Levin (14:364-365), Hoerr and Moore have observed that the area of contact or the length of the constriction affects both the control of air coming from the esophagus and the frequency of the vibrations. The longer constrictions (greater mass) were said to result in a lower pitch and a harsher voice.

Various methods of air intake and expulsion, as well as their relationship to speech production, have been explored in detail by DiCarlo (7), Diedrich (8), and others. Oral air pressure and neoglottal tonus have been measured by various types of pressure studies (8, 11). In the time domain, experiments were performed to determine the number of words and syllables spoken with one charge of air, the rate of speech in words per minute, and the length of time necessary to inject a charge of air (6, 24, 27). Berlin (3) reported that vowels were sustained an average of 2.37 seconds by good esophageal speakers and 0.98 seconds by poor speakers.

Many other investigators have attempted to relate the excellence of alaryngeal speech to frequency measures and the description of pitch, pitch inflection, and pitch variations (1, 2, 6, 14, 25, 26). Mean fundamental frequency measurements ranged from 62.8cps (24) to 94.38cps (23) for superior speakers.

Little experimental evidence is available on the relative loudness or intensity of esophageal speech. Hyman (10) reported significant differences among speakers using an artificial larynx, esophageal speech, and normal speech. Sound pressure levels, above a reference of 50db relative to 0.0002 dynes/cm^2, were: 33db for the artificial larynx group, 29db for the normal group, and 23db for the esophageal group. McKinley (18) found alaryngeal speakers to be using significantly less intensity and significantly greater duration than normal speakers in the production of stressed syllables in words. Klein (12) found that good esophageal speakers could increase the loudness of their voices when asked and that the Lombard reflex operated in esophageal speech as it does in normal speech. In addition, Klein (12) discovered that good esophageal speakers gained greater loudness when speaking in white masking noise than they did when they were simply asked to speak as loudly as they could.

Spectographic analyses of the esophageal voice have shown certain resonant patterns to be typical of superior speakers (13, 26, 27, 28). The results of these studies also indicated a relationship between frequency and amplitude characteristics of esophageal phonation. The amplitude patterns of prolonged vowels demonstrated fluctuating pressure as the neoglottis emitted puffs of air. Van den Berg (2) stated that in esophageal speech a "low pitch is produced with a low intensity of voice, a high pitch with a high intensity." He attributed this relationship to the Bernoulli effect.

Factors contributing to over-all intelligibility or acceptability of esophageal speech provided another area of investigation (7, 24, 30). In the most recent experiment, Shipp (24) had judges rate 33 esophageal speakers on acceptability of speech and respiratory noise prominence. Voice wave recordings of the second sentence of "The Rainbow Passage" (9) were obtained by means of a Honeywell Visicorder. These wave recordings were categorized as (a) quasi-periodic phonations, (b) unmeasurable phonations, or (c) silence. Only quasi-periodic wave segments were measured by an electronic reduction system. The following statistics were computed: mean, standard deviation and 90 percent range of fundamental frequency; total duration; and percentage of entire utterance spent in quasi-periodic or measurable phonation, aperiodic or unmeasurable phonation, and silence. Intercorrelations, as well as multiple correlations, were performed among all of the physical and perceptual data. A larger percentage of the recordings of poor speakers was reported to be aperiodic, but no quantitative basis for judgments of aperiodicity was given. Shipp suggested, from the multiple correlation data, that the two best predictors of alaryngeal speech acceptability were standard deviation of the fundamental frequency and prominence of respiratory noise.

Several writers noted that the vocal quality of esophageal speech differed from the quality of laryngeal voice (13, 25). Snidecore (26:101) equated this deviation in quality with hoarseness which Levin (14:366) reported may be partially attributed to secretions in the pharyngeal sac or diverticular enlargements. As mentioned previously, Hoerr and Moore (14:364) suggested that the degree of harshness in esophageal speech may be a function of the mass of the neoglottis. However, no quantitative research concerning the voice quality of alaryngeal speech was found in the literature.

III. LITERATURE RELATING LARYNGEAL TO ALARYNGEAL VOICE PRODUCTIONS

Voice quality in laryngeal speech, as described by Fairbanks (9), is "a property of all voiced intervals, but is significant primarily during vowels." Therefore, vowels appear to provide most of the auditory cues for perception of vocal quality. In addition, the findings of Sherman and Linke (23) indicate that physiologically low vowels are judged to have a harsher quality than physiologically high vowels.

Researchers have attempted to correlate undesirable phonations of intact larynges with the time patterns of the glottal openings (4, 5, 14, 16, 21, 22, 30). Initially, rapid random variations in fundamental frequency were quantitatively related to roughness, harshness and/or hoarseness. Further experimentations centered around the quasi-random amplitude variations as a possible consequence of laryngeal function

(5, 34). One investigation (33), using computer techniques, simulated laryngeal amplitude variations and obtained perceived judgments of roughness. Wendahl (33) assigned the term "shimmer" to irregular amplitude variations.

One of the most significant and persistent reports of the deviant, yet anatomically intact, productions of the human larynx has been associated with what Wendahl (32, 33, 34) terms "jitter." Jitter refers to rapid random variations in periods between glottal pulses and has been significantly correlated with perceived vocal roughness or harshness. Perhaps the regularity with which the impulses from the esophagus reach the supra-pharyngeal tract is related to judged excellence in esophageal phonations, as is the case in normal speech. Hence, to extend the research on jitter in laryngeal speech to that of alaryngeal speech appeared to be logical and informative.

From the literature it also seemed possible that irregularities in time periods of esophageal vibrations would not be perceived as undesirable elements in this type of phonation. The basilar membrane of the inner ear may respond differently to very low frequency because it is allowed a longer resolution time between impulses. Michel's study (19) tends to support this view. He found a continuum in the degree of wave to wave variations among subjects--normal voices had the smallest degree of jitter, harsh voices had more, and vocal fry phonation produced by normal speakers had the greatest amount of jitter (see Table I). However, listeners did not classify vocal fry as being harsh, but judged the groups to be two different types of phonation. Michel (19) proposes that the perception of the pulse-like character of vocal fry overrides the differences in wave periods.

The vocal fry group had a mean fundamental frequency of 36.4cps with a range of 30.7 to 43.7cps, whereas the harsh voices had a mean fundamental frequency of 122.1cps with a range of 103.7 to 180.0cps (see Table I). In comparison, mean fundamental frequencies given for groups of superior esophageal speakers ranged from 62.8cps (24) to 94.4cps (23). Since mean fundamental values for esophageal speakers appeared to fall between those found for harsh and vocal fry phonation, listeners may or may not attend to differences in the periods of wave to wave variation. Therefore, it appeared worthy to investigate the relative importance of the regularity of esophageal vibratory activity with regard to listener ratings of speech superiority.

TABLE I

ACOUSTICAL DATA RELATIVE TO NORMAL, HARSH, AND VOCAL FRY PHONATIONS*

Quality	Mean Fundamental Frequency	Mean Perturbation	Mean Range
Normal Phonation	112.6cps 9.08msec	.60cps .0498msec	3.8cps
Harsh Phonation	102.0cps 10.41msec	1.58cps .1467msec	7.7cps
Vocal Fry Phonation	30.1cps 36.68msec	2.30cps 3.7970msec	12.9cps

*Mean fundamental frequency, perturbation factor (jitter) around the mean fundamental frequency, and range of perturbations for sustained /a/ phonation. (19)

CHAPTER II

PROCEDURE AND ANALYSIS

Wave forms of esophageal speakers phonating the vowel /æ/ were measured and the ratio differences between the Hertz (Hz) of adjacent waves were computed. This jitter data, mean fundamental frequency, and ratings of wetness were compared with listener judgments of voice pleasantness. Judgments of vocal quality were obtained by two techniques: paired comparisons and a rating scale.

I. PROCEDURE

Subjects. Eight alaryngeal speakers were selected for this study. They were judged to be using esophageal speech by two trained speech pathologists. The only requirements placed on the subjects were that they be able to phonate a single vowel /æ/ for at least 750 millisecond duration, and that they be in good health at the time of recording. The subjects finally selected had been using alaryngeal speech from one to eight and one-half years, had received from three weeks to six months of formal speech training, and ranged in age from 48 to 69 years.

Testing Equipment and Materials. Each subject phonated across an Electro Voice, Model 641, microphone placed six inches from the lips and slightly to the right of the midline. The tapes were made on an Ampex P.R. 10 recorder. The choice of the vowel /æ/ was based on research by Sherman and Linke (23). Since they related perceived harshness to low rather than high vowels, it seemed appropriate to use a vowel that would provide the best sample of the measurable correlates of harshness if they are present in alaryngeal speech.

Recording Procedure. The subjects were instructed to sustain the vowel /ae/ as long as possible and allowed to practice as much as they desired prior to the actual recording. Several tapings of the same vowel were made for each subject. A sound-treated audiological suite was used for all of the recordings. The VU level meter was adjusted to 0 for the recording of each subject. In order to eliminate the effect of stoma noise on listener's judgments of pleasantness and on the wave form patterns, subjects were instructed to gently obstruct the stoma with a piece of gauze during the phonation, if stoma noise was present.

Test Tape Construction. The original taped phonations were altered to splice out, on a diagonal cut, the center 750 milliseconds of each production so the tape recordings of all subjects would be equal in duration. Of the phonations for each subject which met the duration criteria, two were randomly chosen and labeled Phonation A and B, respectively. The center section of each phonation was then made into a tape loop and dubbed onto another P.R. 10 recorder until a sufficient number of stimuli for each subject was obtained. Two master tapes were compiled. First, dubbings of the 'A' phonation for each subject were spliced together in a paired-comparisons design so that every subject was paired with every other subject. Five of these pairs were repeated to provide test-retest reliability. The interpair silent time was one-half second and the intra-pair time for judgment was four seconds. The resulting 33 stimulus pairs were randomized according to a table of random numbers. Ten practice items also arranged in paired-comparisons, but composed of 'B' phonations, preceded the test items.

A second master tape consisted of five presentations of both 'A' and 'B' phonations for each subject in a non-paired design. These 80 phonations were randomized with a four-second silent interval between stimuli to allow time for rating.

Measurement Procedure. Each 750 millisecond phonation was played through a Honeywell Visicorder run at a speed of 120 inches per second. A calibration line was also recorded every .01 second which resulted in the time lines being approximately 30 millimeters apart. The distances between time lines were measured and computations made accordingly. To improve accuracy, perpendicular lines were made to intersect the point of the largest peak in each wave. Each period was then measured by caliper and ruler techniques with estimates to the nearest 0.1 millimeter. Frequency in cycles per second (Hertz) was computed by dividing the measured length of the wave and then multiplying this figure by 100:

$$\text{Frequency} = \frac{\text{time length}}{\text{wave length}} \times 100$$

Judges. Judges were selected only upon their availability and no stated loss of hearing. No audiologic procedures were used to evaluate hearing ability. A total of 34 judges was obtained, ranging in age from 19 to 44 years with a mean age of 27 years. They were all students at the University of Houston, majoring primarily in Speech Pathology or Education. None of the judges were experienced in working with laryngectomees or otherwise closely associated with an esophageal speaker.

Instructions to Judges. On the first tape (paired stimuli), the judges were instructed to be prepared to listen to pairs of sounds and to judge which in each pair sounded the most pleasant. No description of pleasant was given. They were only asked to choose the voice that they would prefer to listen to if they had to listen to one of them over a prolonged period. They were encouraged to ask for repeats as many times as they wanted, but they were forbidden to leave a blank for a pair or to call both phonations equal. On the second tape, the judges were instructed to rate each phonation on a seven-point rating scale, with one representing the most pleasant voice and seven, the least pleasant.

Informal pilot listening made the writer aware of a quality which seemed to relate to Moore's description of wet and dry hoarseness (20). After the presentations noted above, sufficient time was available to play the second tape again for ratings of "wetness"; one, indicating the least wet, and seven, the most wet.

Playback Procedure. Playback for listener judgments was achieved through paired KLH Model 10 electrostatic speakers in sound-treated audiological suites. Sound output was adjusted to an approximate sound pressure level of 75db at thecenter of the listening group.

II. ANALYSIS

Parametric: Data obtained from the rating scales were treated parametrically.

Hypothesis I: Significant 'judges' effect, differences among judges, and significant 'presentations' effect, differences among presentations.

Design: Lindquist (17) Type AxBxS, two within dimensions.

Data: Judges ratings of pleasantness for each of the 5 presentations of each phonation.

Judges ratings of wetness for each presentation of each phonation.

If Hypothesis I yields no significant 'judges' or 'presentations' effect, a single presentation, arbitrarily selected, may be used as score data.

Hypothesis II: Significant differences among subjects.

Design: AxS, 1 within and 1 between dimension.

Data: The judges ratings for the third presentation of each phonation were taken as judgments to produce an errorterm for testing the hypothesis.

Hypothesis III: Relatively low correlations among independent variables and relatively high correlations among the dependent and independent variables, suggesting that the latter may contribute significantly to judged pleasantness.

Procedure: Intercorrelation matrix.

Dependent variable: Mean ratings of pleasantness for each phonation of each subject.

Independent variables: Mean ratings of wetness for each phonation of each subject.

Mean jitter ratios for each phonation of each subject.

Mean fundamental frequency for each phonation of each subject.

If Hypothesis III is confirmed, then Hypothesis IV will be tested.

Hypothesis IV: Pleasantness can be predicted from measures of wetness, fundamental frequency, and jitter.

Design: Multiple regression equation.

Data: Same as for Hypothesis III.

Nonparametric. Judgments of pleasantness for each subject were summated and the subjects were then ranked on a scale from most to least pleasant. The subjects were also ranked according to jitter ratios and wetness ratings--one, representing the most jitter and wetness, and eight, the least. In addition, the subjects were ranked from the lowest to the highest mean fundamental frequency. These rankings were used to compute rank order correlations between and among the dependent and independent variables.

Acoustical. Analysis was made by hand measures of the speech wave periods produced by the center 750 millisecond portions of the phonations of eight alaryngeal speakers. The frequency in cycles per second (Hertz) was computed first. The ratio differences between adjacent cycles were obtained in order to measure the mean extent of cycle to cycle variation (jitter) for each subject and to compare subjects. A ratio of one period to the next was needed because the auditory effect of cycle to cycle differences in frequency is related to the value of the differences in tones. It did not matter whether the change in period was in a positive or negative direction, so the smaller Hertz figures were always divided into the larger. For example, consider a series of three waves found to have the following measurements, respectively: 176Hz, 161Hz, and 196Hz. Jitter ratios would be computed in this manner:

$$\frac{176}{161} = 1.09; \qquad \frac{196}{161} = 1.22$$

Mean fundamental frequencies were computed by adding the Hertz figures and dividing by the number of figures.

CHAPTER III

RESULTS AND DISCUSSION

In the previous chapter it was stated that listeners were asked to perform three tasks: one, to judge between paired phonations for all speakers; two, to rate two utterances for each subject on a seven-point scale for degree of pleasantness; and three, to rate, on the same scale, the degree of "wetness" in the voices. For clarity of presentation, the statistical results will be presented in two parts: Part One includes parametric treatment of the data; Part Two includes nonparametric treatment of the data. In this study, listeners were asked to make judgments of the quality of utterances produced by alaryngeal speakers. They were specifically asked to judge pleasantness without regard to how they might respond if normal speakers had been included in the sample. Therefore, any generalization made from this study must be limited to esophageal speakers.

I. PARAMETRIC RESULTS

The first hypothesis tested in the parametric analysis stated that there was a significant 'judges' and 'presentations' effect. An AxBxS design was repeated for each phonation; the A dimension, presentations, and the B dimension, judges. The $_{.05}F$ values for pleasantness of Phonation A for presentations, judges, and presentation x judges interaction are 1.91, df=4, 28; 0.67, df=33, 231; 1.27, df=132, 924, respectively. Phonation B ratings of pleasantness $_{.05}F$ values for presentations were 0.87, df=4, 28; for judges, 0.78, df=33, 231; and for presentations x judges interaction, 1.12, df=132, 924. Tabled F values appropriate for this hypothesis were: $_{.05}F(df=4, 28)=2.71$; $_{.05}F(df=24, 120)=1.61$. None of the obtained F values were significant. Table II gives the mean ratings for each of the five presentations of Phonations A and B across all subjects and judges. Table III gives the mean ratings of each judge over all presentations and subjects for each phonation.

The ratings for "wetness" were subjected to the same analysis. The $_{.05}F$ values for presentations, judges, and presentations x judges interaction, respectively, for phonation A were as follows: 1.64, df=4, 28; 1.06, df=33, 231; 1.78, df=132, 924. The presentations x judges interaction was statistically significant (see tabled F values above), but does not appear to be of operational significance. No other F values were significant. For phonation B judgments of wetness, the $_{.05}F$ value for presentations was 5.16, df=4, 28; for judges, 0.71, df=33, 231; and for presentations x judges interaction, 1.43, df=132, 924. These results suggest a significant 'presentations' effect, but this was apparently associated with the first presentation only. There was a 0.5 rating point difference between the first presentation and all others, but the remaining four mean ratings were nearly equal (see Table II). Since these ratings required a change in listening task, the judges may have had difficulty adjusting to the new set. The large number of judgments relative to the few presentations may have further amplified this F value. There was not a significant 'judges'

TABLE II

RATING MEANS ACROSS JUDGES AND SUBJECTS FOR ALL PRESENTATIONS OF 'A' PHONATIONS AND ALL 'B' PHONATIONS

Presentation:	1	2	3	4	5
Pleasantness A	4.71	4.70	4.65	4.61	4.49
Pleasantness B	4.61	4.83	4.79	4.67	4.59
Wetness A	4.14	4.45	4.34	4.47	4.51
Wetness B	4.10	4.51	4.52	4.69	4.57

TABLE III

PLEASANTNESS (Pl) AND WETNESS (W) RATING MEANS ACROSS SUBJECTS AND PRESENTATIONS FOR EACH JUDGE

Judge Number	Pl_A	Pl_B	W_A	W_B
1.	4.72	4.82	4.27	4.52
2.	4.57	4.55	4.62	4.75
3.	4.70	4.92	4.22	4.47
4.	4.87	5.30	4.65	4.57
5.	4.60	4.52	4.57	4.60
6.	4.47	4.87	3.95	4.50
7.	4.15	4.10	4.90	4.90
8.	5.17	4.62	4.85	4.67
9.	5.10	5.02	5.05	4.72
10.	4.70	5.05	4.75	4.65
11.	4.42	4.50	4.62	4.67
12.	3.92	4.12	4.70	4.62
13.	4.82	5.00	4.00	4.10
14.	4.12	4.40	4.12	4.22
15.	4.55	4.42	4.15	4.10
16.	4.45	4.75	4.30	4.32
17.	5.37	5.55	3.32	3.57
18.	5.02	4.70	4.60	4.67
19.	4.47	4.47	4.22	4.32
20.	5.12	5.00	4.32	4.37
21.	3.85	3.60	4.35	4.17
22.	4.57	4.45	4.25	4.30
23.	4.15	4.42	4.30	4.37
24.	4.77	4.65	4.07	4.65
25.	4.77	5.05	3.35	3.82
26.	4.47	4.72	4.52	4.72
27.	4.55	4.62	4.10	4.60
28.	4.95	5.15	5.32	5.42
29.	4.87	4.85	3.77	3.85
30.	4.85	4.90	4.40	4.55
31.	4.52	4.40	4.45	4.30
32.	4.35	4.62	5.07	5.25
33.	5.30	5.20	4.05	4.10
34.	4.17	4.37	4.75	4.82

effect or interaction between judges and presentations. The mean ratings of each presentation of both Phonations A and B are presented in Table II, and the mean ratings of each judge for both phonations across presentations and subjects are listed in Table III. Only one of the F values was significant. Considering the total number of F values obtained, this could, in part, be due to chance, and, in part, to the explanation given above. The hypothesis that there was 'presentations' or 'judges' effect on the ratings of pleasantness and wetness was rejected.

The second hypothesis stated that there was a significant 'subjects' effect--a meaningful difference among subjects for judged pleasantness and wetness. Results were obtained from an AxS design: the A dimension, judges ratings, provided the error term. Since there was not a significant presentations effect, the third presentation for each phonation was selected as data. The $_{.05}F$ values concerning pleasantness were 5.36 for phonation A and 5.27 for phonation B. The ratings of wetness were also used in the same design with the following results: $_{.05}F$ values for subjects was 26.23 for phonation A and 32.90 for phonation B. The <u>tabled</u> <u>F</u> <u>value</u> appropriate for this hypothesis was $_{.05}(df=6, 120)=2.17$. All of the F values were significant, indicating that the subjects were judged to be different in terms of pleasantness and wetness.

The possible correlates of esophageal voice quality within the scope of this study were ratings of wetness and objective measures of jitter and fundamental frequency. Rating and measurement data for all the variables are given in Table IV. Mean ratings for each subject's phonations were obtained by averaging the ratings given by all judges for all five presentations of each phonation. Since presentations or judges effects are considered nonsignificant, these mean ratings were used as data for linear correlation procedures. Table V presents the intercorrelation matrix for all variables in this study.

Perceived pleasantness was the dependent variable; all others were independent variables. Ideally, intercorrelations of the dependent variable with the independent variables should be moderate to high, and the intercorrelations among the independent variables, low, in order for a multiple regression equation to provide useful information. Inspection of the correlation matrix indicated that this was a distinct possibility.

Inasmuch as 'A' and 'B' represented two phonations chosen randomly from a short series of consecutive phonations, one would assume esophageal performances for a given subject to be similar. Therefore, the correlations between A and B phonation for each of the variables were expected to be high. This result was found for all measures except jitter. The correlation between jitter A and jitter B was 0.07, which may have reflected measurement error. The difficulty in obtaining valid Visicorder analysis will be considered later.

The multiple regression correlation coefficient between the dependent variable and the independent variables was 0.87 for phonation A and 0.79 for phonation B. Referring back to the linear correlations, "wetness" ratings were found to make the largest contribution to the

TABLE IV

RAW DATA*

Subjects	Pl_A	Pl_B	W_A	W_B	J_A	J_B	FF_A	FF_B
I.	4.12	4.19	3.62	2.86	1.56	1.19	139	79
II.	3.82	3.77	2.55	2.58	1.02	1.04	42	42
III.	4.68	4.70	5.55	5.72	1.47	1.63	62	74
IV.	4.74	4.76	5.36	5.41	1.41	1.66	84	107
V.	5.71	5.57	6.02	6.24	1.52	1.68	88	84
VI.	4.89	5.13	4.72	5.83	1.38	1.27	145	144
VII.	4.95	5.38	3.93	3.86	1.75	1.38	95	90
VIII.	4.08	4.09	3.31	3.34	1.06	1.76	21	45

*Mean ratings of pleasantness for each phonation (Pl_A and Pl_B) of each subject.

Mean ratings of wetness (W_A and W_B);

Mean jitter ratios (J_A and J_B);

Mean ratings of fundamental frequency (FF_A and FF_B).

TABLE V

INTERCORRELATION MATRIX*

	Pl_A	Pl_B	W_A	W_B	J_A	J_B	FF_A	FF_B
Pl_A	1.00	0.96	0.84		0.62		0.34	
Pl_B		1.00		0.76		0.34		0.65
W_A			1.00	0.95	0.50		0.27	
W_B				1.00		0.53		0.64
J_A					1.00	0.07	0.64	
J_B						1.00		-0.03
FF_A							1.00	0.79
FF_B								1.00

*Computed from mean ratings of pleasantness (Pl) and variables of wetness (W), jitter (J), and fundamental frequency (FF) for each phonation (A and B).

judgments. Since this study was designed to explore quantitative measures of jitter and fundamental frequency in relationship to pleasantness, a multiple regression for pleasantness, using only these measures as independent variables, was obtained. For Phonation A, the coefficient was 0.63. The linear relationship between pleasantness and jitter was 0.62, which indicated that fundamental frequency did not contribute significantly to judgments of pleasantness. On Phonation B, the coefficient was 0.75 and the linear relationship between pleasantness and fundamental frequency was 0.65. In this instance, jitter appeared to be a non-contributing factor to the judgments. The correlations between pleasantness (Pl), jitter (J), and fundamental frequency (FF) for Phonations A and B appeared paradoxical. The linear correlations for these variables on Phonation A (Pl and J, 0.62; Pl and FF, 0.35) were almost exactly reversed in the case of Phonation B (Pl and J, 0.34; Pl and FF, 0.65). In multiple regression analyses, it is somewhat arbitrary as to just which variable will be taken first in the regression. From the above analyses, it was not possible to determine the relative importance of jitter and fundamental frequency for the prediction of judgments of pleasantness. In general, it would appear that either one of these variables accounted for a modest portion of the variance in the judges' ratings of pleasantness. However, eight subjects constitute a rather limited sample for making such generalizations.

II. NONPARAMETRIC RESULTS

In Part One, the analyses showed that the two phonations of each subject were similar according to listener judgments of pleasantness. The linear correlation between pleasantness ratings for Phonations A and B was 0.96. The rank order correlation (rho) between the two utterances for each subject was unity (see Table VI), and so the two phonations were considered as one. This finding was critical to the rest of the nonparametric analysis, as it provided the rationale for using combined data from both phonations for the other variables. By treating the two phonations as one, the effect of measurement error should be reduced. There would be no need to stress this point were it not for the fact that paired-comparisons data were derived from 'A' phonations only.

Table VII presents the data from the paired-comparisons judgments of pleasantness and the rankings obtained from this procedure. The rho between the pleasantness judgments for the two techniques was 0.81.

Only the paired-comparisons rankings of pleasantness were used in the remainder of the nonparametric analysis. Table VIII shows the mean data from the combined phonations and the corresponding rankings for the independent variables which were used to compute the rank order correlations (rhos) given in Table IX. Subjects were ranked according to jitter, with rank one representing the highest jitter ratio and rank eight, the lowest. The rho between jitter and judged pleasantness was -0.46. This correlation was taken to mean that the amount of jitter present in the acoustic signal may affect judged pleasantness of voice adversely.

TABLE VI

MEAN RATINGS OF PLEASANTNESS AND CORRESPONDING RANK
FOR EACH SUBJECT

Subject Number	Phonation A		Phonation B	
	Mean Rating	Rank	Mean Rating	Rank
I.	4.12	3	4.19	3
II.	3.82	1	3.77	1
III.	4.68	4	4.70	4
IV.	4.74	5	4.76	5
V.	5.71	8	5.57	8
VI.	4.89	6	5.13	6
VII.	4.95	7	5.38	7
VIII.	4.08	2	4.09	2

TABLE VII

SUMMATION OF PLEASANTNESS JUDGMENTS FOR EACH SUBJECT FROM PAIRED-COMPARISONS PROCEDURE AND CORRESPONDING RANK

Subject Number	Number of Judgments	Rank
I.	159	1
II.	150	2
III.	137	3
IV.	112	6
V.	48	8
VI.	102	7
VII.	113	5
VIII.	131	4

TABLE VIII

MEAN DATA AND RANK FOR INDEPENDENT VARIABLES
PHONATIONS A AND B COMBINED*

Subject Number	J	Rank	W	Rank	FF	Rank
I.	1.37	6	3.24	7	109	7
II.	1.03	8	2.56	8	42	2
III.	1.55	3	5.63	2	68	3
IV.	1.53	4	5.38	3	90	5
V.	1.60	1	6.13	1	86	4
VI.	1.32	7	5.27	4	144	8
VII.	1.56	2	3.89	5	92	6
VIII.	1.41	5	3.32	6	33	1

*Mean jitter (J) ratios and wetness ratings (W) ranked from most to least. Fundamental frequency (FF) ranked from low to high.

Next, pleasantness was compared to "wetness" or "spittiness" of the phonations. The speakers were ranked from the most wet to the least wet according to mean ratings. The rho between pleasantness and wetness was -0.72. This result indicated that esophageal speakers who were least "spitty" in their utterances would be most acceptable to listeners.

The third factor considered was that of mean fundamental frequency. The subjects were ranked from the lowest mean phonational frequency to the highest. The rho between pleasantness and mean fundamental frequency was 0.24, which indicated that fundamental frequency was not related to judgments of pleasantness.

A comparison was then made between judgments of wetness of phonation and the amount of measured jitter in the electroacoustic signal. The rho was 0.74. With a correlation of the magnitude between primary variables, it would be difficult to state whether judgments were made on the basis of wetness or jitter.

Comparisons were also made between mean fundamental frequency and wetness and jitter. The rho between fundamental frequency and wetness was 0.10, and the rho for fundamental frequency and jitter was -0.05. These data indicated that fundamental frequency was not related to wetness or jitter.

Five items were repeated in the paired comparisons presentations to establish test-retest reliability. The rho for test-retest ranked comparisons for all subjects was 1.00, indicating that judges were able to distinguish between phonations and to judge the same speaker similarly on repeated presentations.

TABLE IX

RANK ORDER CORRELATIONS*

Variables	Rho Correlation
Pleasantness and Fundamental Frequency	0.24
Pleasantness and Jitter	-0.48
Pleasantness and Wetness	-0.72
Jitter and Fundamental Frequency	-0.05
Jitter and Wetness	0.74
Wetness and Fundamental Frequency	0.10

*Pleasantness judgments from paired-comparisons

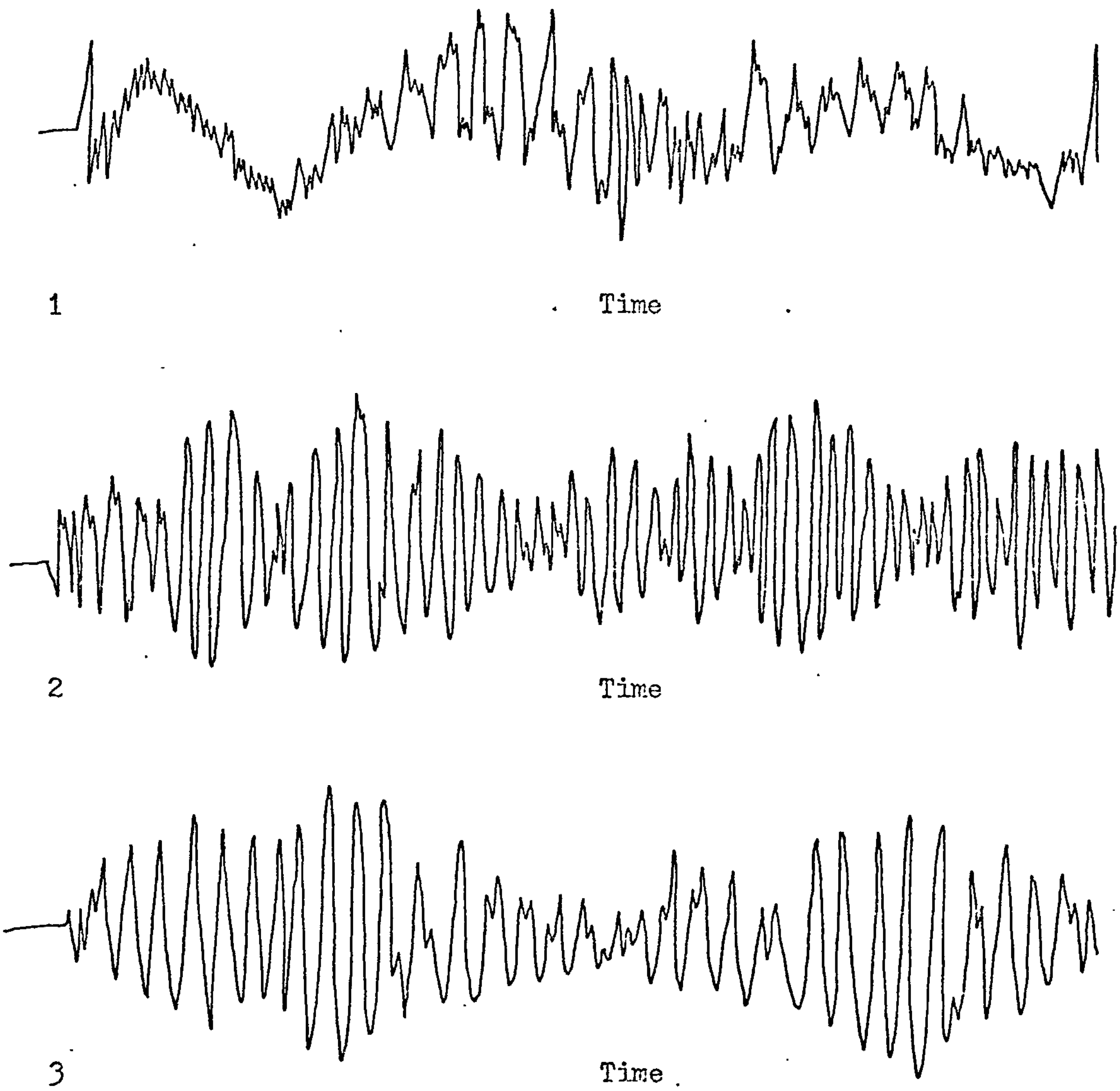
III. DISCUSSION

From both methods of treating the data, one would assume that fundamental frequency, as an entity, is unrelated or only slightly related to judgments of pleasant voice quality for esophageal speakers. This result was not anticipated since one would assume laryngectomees approximating the model speaking level of normal speakers would be more acceptable. An expected result relating esophageal voices with greater amounts of jitter to judgments of unpleasantness was not conclusive. The data indicated only that some relationship might exist between the amount of jitter in the acoustic signal and listener judgments of pleasantness. There was also some evidence that ratings of "wetness" were related to the amount of jitter in the signal. This study was not definitive, however, and the interpretation of the results relating jitter to pleasantness must be made with extreme caution. Some caution should be taken even before accepting the statements regarding fundamental frequency. Figure I is a tracing of one Visicorder record. A cursory inspection of the figure will show the viewer the extreme difficulty that the writer had in making measurement decisions. The population of alaryngeal speakers available at the time that the study was instigated was small and few were considered superior esophageal speakers. Most of the records were extremely difficult to interpret, and the writer was not confident that all measurement decisions were correct. The tape recordings were sent to a laboratory at a different university for electronic processing, but that laboratory was unable to process wave forms of the complexity as shown in Figure I.

On a theoretical level, the wave forms sometimes suggested that there was not only one air bubble exciting the vocal tract, but perhaps as many as two or three. The wave forms also suggested that the air flow was not a simple envelope of onset, but a gradual set of openings. These tracings cannot be adequately described verbally; the reader shoald consider Figures II and III. From these wave forms, one could assume a number of separate pulses or a gradual set of openings. Figures for fundamental frequency computed from either assumption would be the same when fundamental frequency is defined as the number of repeated events that occur in a given period of time. However, jitter ratios would vary depending on whether the wave forms were judged to be separate pulses or gradations of the same opening if adjacent pulses were compared rather than repeated events. The writer has implicitly made the assumption that jitter should be measured from the fundamental frequency, assuming the previous definition. Thus, the jitter measures are more open to question than those of fundamental frequency.

The relationship between "wetness" and pleasant voice quality is one that the writer feels was established even with the small sample used. Listeners expressed opinions that they found the "spitty" voices repulsive to hear.

The relatively low correlation between jitter in esophageal phonations and unpleasantness of auditory experiences is interesting to speculate upon. If one assumed that the measurement decisions were all correct, the low correlation could be explained by relating low funda-



FIGURES 1, 2, and 3

TYPICAL VISICORDER TRACINGS OBTAINED FROM ESOPHAGEAL SPEAKERS mental frequency esophageal speech to low frequency vocal fry. Vocal fry is typified by high amounts of jitter and the jitter in vocal fry is not perceived as rough by listeners (19). The same amount of jitter in vocal productions of higher fundamental frequencies would definitely be considered rough. The explanation for this phenomenon probably lies in the resolution time for the basilar membrane. If the membrane is allowed to critically damp between excitations, or if the successive excitations are rapid, but cause the membrane to be distorted at the same relative place, the tone will not be perceived as rough. Exploring listener perceptions of low frequency jitter programs should provide the answer to the question. This has not yet been done, but the basic design already exists, and such a study will be started within the next few months (35).

An investigation of shimmer (rapid, random variations in amplitude) in the wave forms of esophageal speakers is also needed. A considerable amount of shimmer was noted in the tracings analyzed in the present study which may have contributed to judgments of unpleasantness.

In the clinical realm, the results of this study indicate that speech clinicians should be concerned with eliminating the "wet" quality of vocal production in esophageal speakers. Training to raise the fundamental frequency in order to approximate that of laryngeal speakers does not appear to improve esophageal voice pleasantness. However, this statement does not imply that the range of frequencies phonated by alaryngeal speakers is irrelevent. Therapy to improve inflectional patterns should be continued.

CHAPTER IV

SUMMARY AND CONCLUSIONS

This study was designed to investigate the relationship between listener judgments of pleasantness of esophageal vocal productions on one isolated vowel and the amount of jitter present in the acoustic signal. Secondary variables were considered. These included the relationship between fundamental frequency and judged vocal pleasantness of phonations and the amount of "wetness" that the listeners perceived in the phonations.

Eight esophageal speakers were asked to phonate the vowel /ae/ several times. From these phonations, two were selected which were longer than 750 milliseconds. The center 750 milliseconds of the two selected phonations for each subject were edited from the tape and prepared for master tapes in two ways. The first procedure was a paired-comparisons design in which every phonation was paired with every other phonation. In the paired comparisons procedure, the first of the two acceptable phonations was used. The two phonations for each subject were then dubbed so that each phonation was available five times for later presentation. For each of the eight subjects, the two phonations were dubbed five times and placed in a random design, so that there were 80 stimulus items which judges were asked to rate on a seven-point scale for the degree of pleasantness in the voices and the amount of wetness that they heard each speaker phonating.

The two phonations were also subjected to Visicorder analysis.

The Visicorder was run at 120 ips. Hand measures were made for each pulse in every phonation. The hand measures were translated into Hz. The Hz measures were used to obtain measures of fundamental frequency and measures of jitter. The definition of mean jitter used in this study was the difference in Hz between adjacent cycles described by dividing adjacent frequencies into each other where the denominator was always the smaller of the adjacent frequencies.

The tapes were played to 34 judges who were asked to perform three listening tasks: to judge which of each pair of stimuli was most pleasant; to rate 80 stimuli on a seven-point scale, the degree to which they would call each phonation more or less pleasant than the others; and to rate 80 items on the degree of "wetness" or "spittiness" that they heard in the utterances.

Parametric procedures were used to analyze the data obtained from the rating scale. Data from the paired-comparisons design were treated nonparametrically. Results of this study lead to the following conclusions:

1. The amount of wetness in production is a strong determinant of judgments of unpleasantness.
2. Fundamental frequency, in and of itself, does not appear to be related to judgments of pleasantness.
3. The amount of jitter found in these esophageal speakers was less important to the judgments of pleasantness than was the amount of wetness in the vocal production.

Hypotheses and suggestions for future research which were proposed are as follows:

1. Jitter in low frequency vocal productions may not be related to acceptability of the utterance. It has been suggested that a study of the perceptual relationships between pleasantness of auditory stimuli and jitter at low mean frequency be undertaken
2. A larger population including a greater number of superior esophageal speakers should be studied. The same factors should be investigated and measurements of shimmer should be obtained.

On the basis of this study, the clinician should work toward eliminating the "wet" voice quality of the esophageal speaker and attend less to fundamental frequency. However, attention should be continued on inflectional patterns.

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APPENDIX

INSTRUCTIONS TO LISTENERS

I. PAIRED-COMPARISONS

Please fill in the blanks at the top of your answer sheet. On the question concerning experience with esophageal speakers, note whether you have observed many or few, worked with esophageal speakers, or have had personal contact with an esophageal speaker.

On this tape you will hear a series of phonations which have been paired. All of the speakers were phonating the same vowel, but only the central portion of each phonation was used. Therefore, the phonation may not necessarily be perceived as a vowel. Your task is to compare the voice quality of the phonations, so try not to attend to intelligibility. Listen to each pair, and decide which one you think has the most pleasant voice--the one you would prefer to listen to if you had to listen to one of them for an extended period of time. Neither of the stimuli may sound pleasing to you, but you have to make a choice between the two. You may not leave a blank indicating that you cannot make a decision. You are also not allowed to check both one and two, indicating that they are equally pleasant in your estimation. If you do either of these on any stimuli, we will have to discard your paper. First, we will play the ten practice items so you can get a general idea of how the speakers sound. Do not mark your papers at this time. Just listen and think about the degree of pleasantness.

Now we will play each pair twice. Do not mark your decision until you have heard the pair the second time. Put a check mark indicating which, either the first or the second speaker in the pair, sounds the most pleasant. If you are not sure of your decision after you have heard the pair the second time, raise your hand and we will play it again. Do not be embarrassed. Some of the decisions are difficult to make. It is up to you to work harder on these and make the best decision you can. Don't feel compelled to keep your first answer if someone else has asked for a repeat and you change your decision. Are there any questions? Now we will begin judging the ten practice items....

Are there any questions? We do the test items in the same way. Be sure and raise your hand if you would like to hear the pair again.

II. RATING SCALE

Pleasantness: Please put your name at the top of your answer sheet. On the next part of this study, you are requested to listen to the same voices and rate each voice on a one to seven continuum. One indicates the most pleasant and seven, the least pleasant. (The rating values were written on the board). The voices will not be in pairs on this tape. You will hear a stimuli and then be given time to rate the voice. First, just listen to the first fifteen voices and think about how you would rate them, but do not mark on your paper. (Play first 15 stimuli).

Now we will begin again with number 1. Please circle the ratings of your choice for each stimuli. If you would like the stimuli played again, please raise your hand. If you change your mind after someone has asked for a repeat, feel free to cross out your first choice and clearly circle your second choice. Are there any questions?

<u>Wetness</u>: Since you're experienced listeners, we'd like for you to do one more task. Some of the voices sound "wet," "spitty," or "gurgly." Do you understand what I mean? If not, raise your hand and we will play an example. O.K. This time rate the voices on a one to seven scale using one to represent the least "spitty" and seven, the most "wet" or "spitty." (Rating values written on the black board). Be as objective as possible and base your judgments only on the "wetness" of the voice. Are there any questions?